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Seasonal Change in Nearshore and Channel Morphology at Packery Channel, A New Inlet Serving Corpus Christi, Texas

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ABSTRACT

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Packery Channel is an artificial inlet that occupies a historic ephemeral pathway between Corpus Christi Bay and the Gulf of Mexico. In 2005, the inlet was opened by Hurricane Emily during its construction and has remained open and navigable for more than 4 years. The shallow-draft channel has not required maintenance dredging despite episodic shoaling during storms, including Hurricane Ike. Stability of the inlet and adjacent beach is attributed to location in the southeast corner of Corpus Christi Bay, receiving augmented ebb flow by wind setup accompanying winter fronts. The ebb current, with speed sometimes exceeding 1.0 m/s, scours sediment deposited during the summer months, thereby maintaining channel depth adequate for water exchange and navigation. After the channel opened, a deposition basin initially served as the main sediment repository for sediment scoured from the bay side. Entrance channel shoaling began to increase in 2008, initiated by 15,000 m^3 of beach sand that entered the channel during Hurricane Ike. Subsequent shoaling is attributed to unrestricted wind-blown transport enhanced by drought. Since completion of the 430-m long dual jetties in 2006, an ebb-tidal delta has not formed. Ebb delta development is suppressed by a strong longshore current and longshore bar formation that alternates in direction seasonally, and by strong bursts of ebb flow during winter. The inlet is located in a region of nearly balanced longshore sediment transport, indicated by near-symmetric shoreline response at each jetty. The shoreline within a 1-km zone of the inlet advanced at a rate of 7.5 m/yr, whereas along the 18-km monitoring area it receded at a rate of 1.6 m/yr, reflecting in part the influence of Hurricane Ike. Channel performance tracks closely with that reported in the original design, with stability to date exceeding those 1997 predictions.

ADDITIONAL INDEX WORDS: *Shoreline change, tidal inlet, tidal current, Hurricane Ike, seasonality, wind fronts, beach profile, beach nourishment, seawall.*

INTRODUCTION

Packery Channel, formally opened in October 2006, is an inlet located on the Texas coast in Corpus Christi along one of several historic ephemeral pathways to the Gulf of Mexico (Figure 1). After many years of discussion, planning culminated with the Packery Channel Feasibility Study, which included the functional design (Kraus and Heilman, 1997) of the navigation channel and dual jetties and a companion report that examined potential change in water circulation and water level in Corpus Christi Bay to the presence of such an inlet (Brown and Militello, 1997). The North Padre Island (Packery Channel), Nueces County, Texas, Storm Damage Reduction and Environmental Restoration Project was authorized in the Water Resources Development Act 1999 as a Federal project with Nueces County, Texas, as the original local sponsor. The City of Corpus Christi assumed local sponsorship in 2000. The primary objective of the project was to increase circulation in the area of Upper Laguna Madre at its intersection with Corpus Christi Bay. In addition, it was envisioned that periodic dredging of the channel would provide a means for nourishing the narrow beach along the North Padre Island seawall. Project milestones and a general background are discussed by Williams *et al.* (2005, 2007).

The narrow, approximately 37-m wide Packery Channel takes a meandering course some 6 km from the Gulf Intracoastal Waterway to the Gulf of Mexico, and it now forms the boundary between Mustang Island and North Padre Island (Figure 2). Average channel depth is 2 to 3 m relative to Mean Sea Level (MSL), but is variable in regions of shoaling (< 2 m) and scour (> 6 m). The straight and parallel jetties constructed of fitted stone are spaced 90 m apart and extend 430 m offshore, corresponding to the offshore limit of the nearshore barred

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14. ABSTRACT

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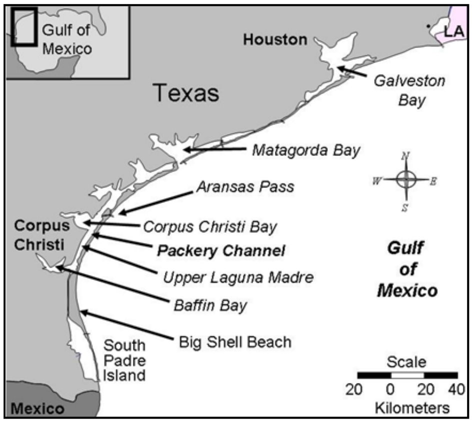

Figure 1. Packery Channel is located along the south-central Texas coast.

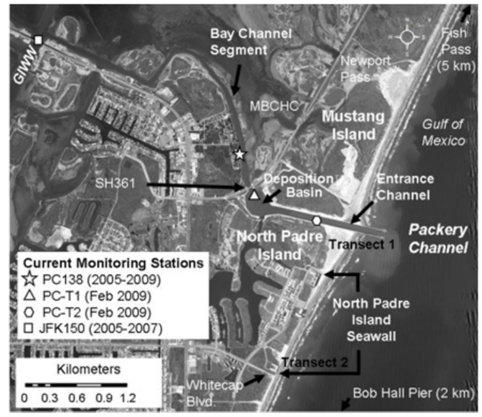

Figure 2. Packery Channel and vicinity including North Padre and Mustang Islands.

region and depths of 3 to 4 m (Kraus and Heilman, 1997; 1998). In addition to its functioning as an environmental enhancement, the channel serves as a popular recreational destination along Mustang and North Padre Islands. On a typical day, visitors to Packery Channel enjoy a variety of activities including fishing, boating, swimming, snorkeling, and kayaking. Consistently strong wind and a weaker longshore current down drift of the inlet makes the area an optimal location for surfing, wind surfing, and kite surfing.

The inlet has remained navigable without maintenance dredging since it was unexpectedly opened during construction by Hurricane Emily in July 2005, a year in advance of completion. The jetties have sustained no significant damage, and the channel has remained navigable to shallow-draft recreational vessels despite inundation and waves during Hurricanes Katrina (August 2005), Rita (September 2005), Dolly that struck the south Texas Coast (Heise *et al*., 2009) in July 2008, and most recently Hurricane Ike that struck the north Texas Coast (Kraus and Lin, 2009; Tirpak, 2009) in September 2008.

A monitoring program of beach profile surveys began prior to construction in August 2003 and continues annually to date, with the Galveston District of the U.S. Army Corps of Engineers (USACE), the USACE Coastal Inlets Research Program, and the City of Corpus Christi as the main sponsors. The program was expanded in 2005 to include measurement of current velocity and quarterly shoreline position and bathymetric surveys. The bathymetric surveys are conducted in the channel and adjacent nearshore, and annual beach profile surveys extend along the 18-km study area from north of Fish Pass to several kilometers south of Bob Hall Pier. Fish Pass is an artificial inlet that opened in 1978 and began closing naturally soon after construction with complete closure in 1985 (Watson and Behrens, 1976; Behrens *et al.*, 1977; Behrens, 1979). Fish Pass is also referred to in literature as New Corpus Christi Pass and the Corpus Christi Water Exchange Pass. Rapid natural closure of the Fish Pass created doubt about the stability of the planned inlet at Packery Channel.

The stability of Packery Channel owes to its efficiency, designed with a small width to depth ratio (Kraus and Heilman, 1997). Cross-sectional stability of the inlet and that of the adjacent beach is attributed to location in two ways. First, the inlet is positioned in the southeast corner of Corpus Christi Bay such that winter fronts directed out of the northwest set up the bay in the corner, reinforcing the ebb flow and effectively scouring the channel, a process first reported by Price (1952). Second, the inlet is located in a region of nearly balanced longshore sediment (mainly sand) transport in the Gulf of Mexico, manifested by the symmetry of the moderate shoreline advance along the beaches to each side, as will be discussed.

Little quantitative knowledge is available on the geomorphic response of the coast to creation of a new navigable inlet. This paper presents results of the monitoring program designed to observe such coastal morphologic adjustment and covers the inlet channel, deposition basin behind it, nearshore, and adjacent beaches, including seasonal changes in morphology and channel shoaling.

METHODS

Nearshore Morphology Surveys

The monitoring program began in August 2003 in anticipation of construction scheduled to start the following month. During the first year, one beach profile survey was conducted on 18 transects along the study reach. In 2005, bathymetry surveys were added to characterize the channel and nearshore as construction proceeded, with supplemental surveys done to document the response of the inlet and adjacent beaches to storms. After construction, the frequency of surveys increased to capture the rapidly changing nearshore and channel morphology, in particular, seasonal variations, as described in this paper. Quarterly surveys were initiated in 2008 to improve understanding of the seasonality of change in nearshore and channel features. Shoreline position surveys were added as an economical method of assessing shoreline change over a broad

area with greater frequency than the labor-intensive beach profile surveys. The monitoring program continues in 2010 in support of proactive channel and beach management by the City of Corpus Christi and research interests by the USACE Coastal Inlets Research Program.

Elevation surveys of the beach, channel, nearshore, and offshore regions are conducted by overlapping three survey methods. The method selected depends upon proximity of structures and depth limitation. Typically, the method and associated nominal depths (MSL) are: 1) a wading survey conducted from the landward limiting feature, such as dune or seawall, to offshore depth of approximately 2 m; 2) a sled survey across the nearshore barred region (1 to 3 m); and 3) single and multibeam sonar surveys in the channel and offshore (3 to 9 m). A 15 to 30-m section of overlap is typically maintained between each survey method. Transect spacing in the nearshore is at 30 m around the inlet mouth, expanding to 60 m to the north and south to allow for interpretation of down-drift change in the longshore bar system. Data are processed to develop digital terrain models for interpretation of morphology and calculation of volume change in the channel and nearshore system. The combination of these survey and analytical methods has provided a detailed data set allowing examination of subtle changes in channel and nearshore morphology that can be interpreted to identify trends in sediment transport.

Surveys are referenced to NAVD88, OPUS Geoid 2003 (Stone, 2006) and tied to local control at Bob Hall Pier and surrounding region to provide continuity between present and previously collected data. Average estimated survey accuracy is +/- 0.05 to 0.06 m for wade and sled surveys, respectively, and +/- 0.09 m for single and multi-beam method, which is attributable to greater range in water depth and variability in seafloor and sea conditions. Depths are given relative to MSL measured at Bob Hall Pier, located 4 km south of the inlet in the Gulf of Mexico, for the present tidal datum epoch, MSL = 0.0 NAVD88, OPUS Geoid 2003.

Shoreline position has been surveyed at least annually since 2004. Measurements are made while driving slowly across and along the beach in a zig-zag pattern with an RTK GPS antenna mounted on a 4x4 vehicle. Elevation is measured at 1.5 to 3-m intervals from the beach-water interface to the most landward possible position defined by limiting features such as the dune toe or seawall. Individual transects are spaced at 1 to 30 m apart. These surveys usually require two days, coinciding with low tide, and are compared to beach profile survey data annually for verification and consistency. Occasionally, the landward extent of the survey is limited, such as due to large amounts of post-storm debris or exceptionally soft sand during extended periods of drought (2008-2009).

For this monitoring program, shoreline position is defined by the elevation of the berm crest as a persistent and unambiguous feature. Berm crest is a morphology-based estimate of position indicating the most landward active shoreline position. The visible beach may be wider on any given day dependent on water level that is a function of tide, wind and wave set up, and storm surge. Beach width is of concern because users can access the beach by vehicle (allowed by the Texas Open Beaches Act, Natural Resource Code, Chapter 16), and resource managers restrict access to sections of the beach along the North Padre Island Seawall based upon a minimum width measured from the base of the seawall. The elevation of the berm crest is typically 1 m (MSL) in the study area, but is dependent on the backshore features and preceding storm conditions and can, therefore, range between 0.6 and 1.2 m. Mechanical movement of sand by beach maintenance crews, such as for seaweed removal and vehicle access, plays a role in short-term changes in morphology near Packery Inlet and near access roads. Although the berm crest was selected for present analysis, measurements are taken across the entire beach face as conditions allow, defining the possible range of shoreline measurement relative to a vertical datum such as MSL and Mean Higher High Water (MHHW), or to another a persistent morphologic feature.

SITE CHARACTERIZATION

Wind and Water Level

Packery Channel is located near two long-term tide stations operated by the National Ocean Service, one in the Gulf of Mexico at Bob Hall Pier called "Corpus Christi," and another located on the Corpus Christi Bay side of the original Packery Channel inland waterway (Figure 2). Water level along the Texas coast is controlled by the astronomical tide and seasonal change in Gulf of Mexico water level, and it is also strongly influenced by local wind (Price, 1952; Kraus, 2007). A seasonal or low-frequency fluctuation in water level occurs with highs in September and October, and lows in January and February. The tide at the Corpus Christi gauge and Packery Channel (at the intersection with Corpus Christi Bay) is diurnal with diurnal ranges of 0.50 m and 0.12 m respectively.

The wind along the Texas Coast is strongly bimodal with persistent southeasterly wind from March or April to August or September (Lohse, 1952). During La Nina years such as 2008 and 2009, drought conditions dominate in Texas, and the duration of southeasterly wind can extend through the winter at stronger-than-average speed. During a typical year, northerly winds accompany frontal passage from September or October to February or March. Southerly winds increase as winter fronts approach, with rapid reversal in direction often doubling in speed as the systems move off the coast (Collier and Hedgpeth, 1950). Wind influences sediment transport both in the channel and in the nearshore. Wind directed out of the southeast and northwest most influence the current in the channel, whereas wind out of the southeast and northeast drive longshore currents that can alter bar formation and alternately cause scour at the tips of the jetties.

Water exchange between Corpus Christi Bay and the Gulf of Mexico is enhanced by the strong wind. Persistent southeasterly and onshore-directed easterly wind force water from the Gulf into the bay, and northwesterly wind forces water toward the Gulf. Prior to opening of Packery Channel, northwesterly wind would set up water in the southeast corner of Corpus Christi Bay at the intersection of the Laguna Madre, causing water level to rise along the flats adjacent to SH361, called the Mollie Beattie Coastal Habitat Community (MBCHC). With a pathway to the Gulf through Packery Channel, water now exits this portion of the bay during frontal passages, greatly enhancing the ebb current flow through the inlet.

Inlet Channel Current

Current velocity is measured at a long-term station (PC138), located 0.4 km north of SH361 Bridge on the west bank of the bay channel segment (Figure 2). The instrument was deployed during September 2005, two months after the channel opened. A side-looking Sontek Argonaut is mounted on an existing structure at mid-depth. Data are collected remotely and posted in real time by radio transfer to the internet (http://lighthouse.tamucc.edu/qc/138). Current velocity is also measured in the Gulf Intracoastal Waterway (JFK150) near the intersection of Packery Channel (http://lighthouse.tamucc.edu/qc/150/).

The current in Packery Channel follows the phase of the tidal signal measured at the Corpus Christi gauge in the Gulf of Mexico (Figure 3). During northwesterly frontal passage, the reinforced current can reach peaks in excess of 1 m/s, and average daily maximum speeds are on the order of 0.5 to 0.8 m/s. Figure 3 shows the response of the current to a sudden reversal in wind direction as a northwest front moved off the coast during December 2008. The current follows the tidal signal on days 8-9 December, which is typical during persistent periods of southeast wind. The range of ebb and flood current speed is similar, peaking at 0.5 to 0.8 m/s. Moderate to strong southeast wind typically precedes frontal systems, and then the wind abruptly reverses as the front moves off the coast. On 10 December, the wind reversal coincided with ebb tide, resulting in an enhanced ebb current in excess of 1.25 m/s. Reinforcement of ebb flow continued for 18 hours. Wind reversals out of the northwest can also subdue the flood signal as seen on day 11 December when the peak sustained flood speed only reached 0.3 to 0.4 m/s. As wind speed dropped after the front and southeast winds gradually predominated, the current returned to phase with the tidal signal.

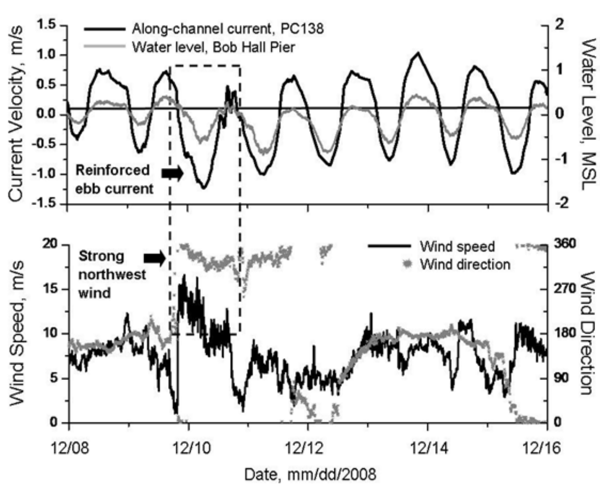

Figure 3. Typical along-channel current velocity measured at Packery Channel and enhanced ebb flow as northwest wind coincides with ebb current during a winter storm.

A complete Packery Channel water velocity record is available for years 2006 through 2008. A partial record exists for 2005 and 2009 (during preparation of this paper), so the statistics do not cover a complete annual cycle for all years listed. For example, weaker current speeds measured through July 2009 do not contain a contribution from the fall season, which is typically the most dynamic time of the year. The tabulated velocity values and those discussed in this paper are an average of all bins across the acoustic beams, which typically extend about 30 m. The mean ebb and flood current speeds are nearly equivalent, varying annually between 0.41 and 0.49 m/s (Table 1). Although the mean current speed has remained relatively constant since channel opening, the peak speed has changed in response to blockage of flow during construction and changes in channel morphology. The maximum or peak speed observed during periods of reinforced ebb current is greater than peak flood speed by as much as 0.7 m/s. The maximum speed of both the ebb and flood current increased during October 2006 as construction reached completion and barriers to flow were removed. The maximum ebb and flood current speed are 1.84 m/s and 1.12 m/s, respectively. From 2006 to 2008, there was a decrease in the maximum ebb and flood, with peaks of 1.29 and 1.19 m/s, respectively, measured during 2008. The decrease in maximum current speed is attributed to widening of the channel by natural processes at the location of the current meter, which may cause the sampling volume to sometimes miss the area of maximum flow. The width of the bay channel segment in this area has increased 6 to 30 m since 2004.

Table 1. *Mean and maximum along-channel current speed at Packery Channel.*

Year	Along-Channel Current Speed Mean, m/s		Max, m/s	
	Ebb (-)	Flood (+)	Ebb (-)	Flood (+)
2005 (Sep-Dec)	0.28	0.28	0.96	1.56
2006	0.48	0.41	1.84	1.12
2007	0.49	0.45	1.64	1.27
2008	0.41	0.42	1.29	1.19
2009 (Jan-Aug)	0.37	0.39	0.94	1.05

RESULTS AND DISCUSSION

Seasonal Change in Morphology

Deposition Basin

Prior to Hurricane Ike, channel shoaling was greatest in the deposition basin (Figure 2), with seasonal shoals developing between the jetties late in the summer and persisting into early winter (Figure 4). From 2005-2007, the southwest quadrant of the deposition basin filled as the bay channel segment was modified by increasing current, upland bank erosion exacerbated by boat wake, and wind-blown sand. A new shoal began to develop at the intersection of the basin and entrance channel

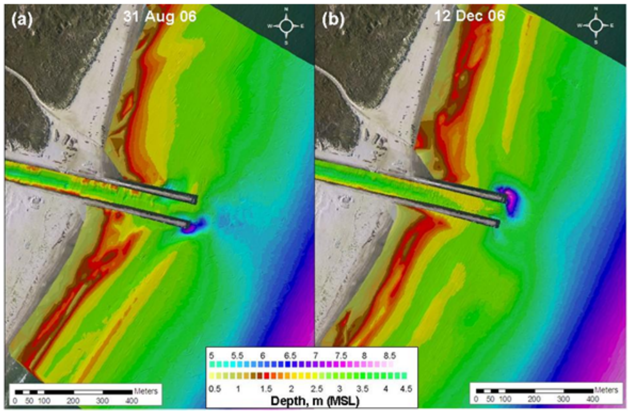

Figure 4. Shoal formation in the entrance channel, (a) 31 August 2006 and (b) 12 December 2006.

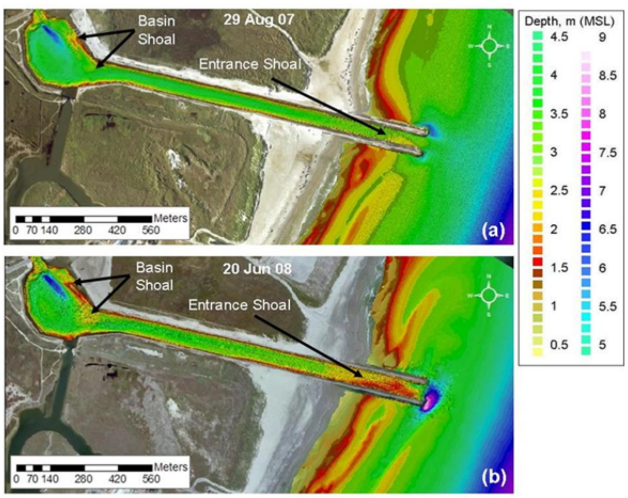

Figure 5. Location and extent of the basin shoal and entrance shoal and nearshore morphology from (a) 29 August 2007 to (b) 20 June 2008.

during the summer of 2007 (Figure 5). By August 2008, the volume of sand in the basin had increased by 11,000 m^3. Minimal shoal growth occurred in the basin after Hurricane Ike, but expansion of the shoal at the intersection resumed from January to June 2009 as the contribution of wind-blown sand increased (Figures 6 and 7). As the basin shoal expanded, the deeper channel (> 2 m) region continued to narrow and shift southward. Channel width at the basin intersection decreased from 61 m in August 2007 to a minimum of 11 m in June 2009. Migration of the shoal northward along the revetment and fronting the boat ramp likely occurred during periods of strong flood current, and shoaling was aggravated by additional sand entering the basin from erosion of the parking area by wind and

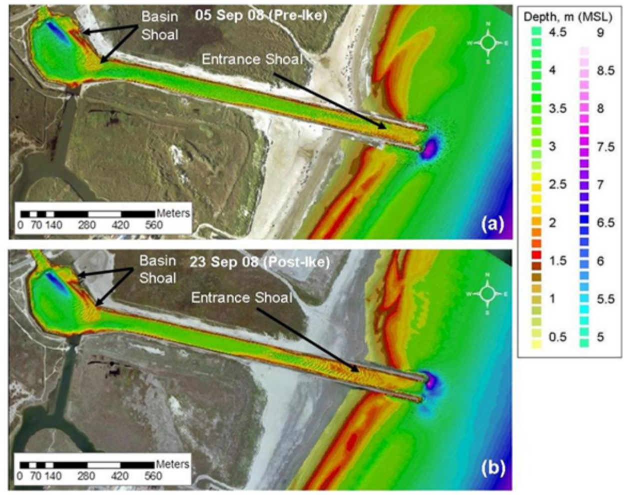

Figure 6. Change in extent of the entrance shoal before (a) 05 September 2008 and (b) after Hurricane Ike 23 September 2008.

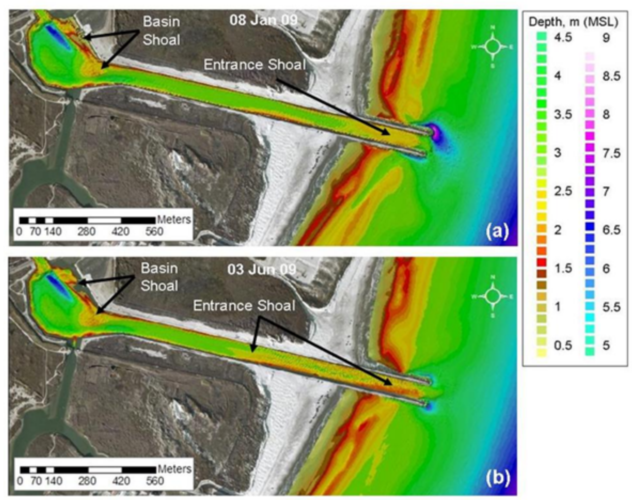

Figure 7. Entrance shoal expands westward from (a) 08 January 2009 to (b) 03 June 2009.

runoff. The boat ramp area was subsequently paved during the summer of 2009.

Sediment deposition occurs as current speed decreases from the maximum measured in the width-restricted channel under the bridge to the expansive basin. Current speed is further limited as the flow encounters a change in orientation at the entrance channel. To verify this interpretation, current velocity was measured at the two temporary stations over a 36-hr period during February 2009 to determine the variability of current relative to channel location. Current velocity measured at the

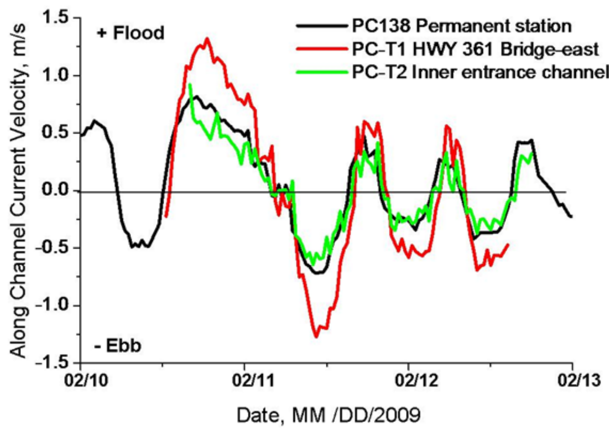

Figure 8. Current velocity measured at three stations located along Packery Channel.

permanent station (PC138) in the bay channel segment across channel from MBCHC was compared to that measured under the SH361 Bridge (PC-T1) and mid-way through the inner entrance channel (PC-T2) (Figure 8). As anticipated, current speed under the bridge, where channel width is restricted, was greater than that measured in the inland channel segment (PC 138) to the northwest as well as the inner entrance channel toward the Gulf of Mexico. During peak ebb and flood flow, current speed in the constricted channel under the bridge was as much as 0.66 m/s greater than that measured in the wider channel segments (PC138 and PC-T2).

Entrance Channel

Shoaling in the entrance channel began after the channel opened in August 2005 and was initially confined between the jetties until Hurricane Ike in September 2008. Prior to Hurricane Ike, sand accumulated between the jetties during the summer, with the shallowest areas located along the south jetty (Figures 4 and 5). During the fall and winter, wind reversals out of the northwest reinforce the ebb current that transport sand toward the Gulf of Mexico. By mid-winter, intermittent periods of enhanced ebb flow would form a shoal at the channel mouth. If winter fronts continued to reinforce ebb flow until spring, the shoal would migrate out of the channel mouth under the influence of the strong current, thereby maintaining channel depth. Seasonal shoaling followed by current-induced channel scour continued until the end of the 2007-2008 winter. After January 2009, strong southeast wind resumed, infrequently interrupted by winter fronts, and continued through the summer. Therefore, the entrance shoal not only remained at the end of winter, but continued building from wind-blown sand transported from the beach into the entrance channel, forming a large emergent shoal in the inner channel along the south jetty. Sand enters the entrance channel predominately by wind-blown transport during the summer when strong southeast wind dominates and blows across the large stretch of the advancing beach south of the inlet. Moderate ebb flow during early 2009 caused the migration of sand toward the mouth, but without the reinforcement by northwest wind this sand merged with the existing shoal. By June 2009, a substantial shoal was located between the jetties, and the windy summer season had just begun.

The 5 September 2008 survey documented the pre-Hurricane Ike condition of the channel and also provides insight into changes that were related to Hurricane Dolly. Hurricane Dolly made landfall in Brownsville 23 July 2008, causing severe shoreline recession at South Padre Island (Heise *et al.*, 2009). The storm surge and waves associated with the approach of Hurricane Dolly scoured the entrance channel as shown in the top panel of Figure 6. It produced a flood current in excess of 0.6 m/s that was maintained for 48 hours, likely forming the channel region along the north jetty. Scour was further enhanced by ebb flow accompanying the exit of flood waters into the Gulf of Mexico.

The entrance shoal became a permanent feature after Hurricane Ike, when 15,000 m^3 of sand entered the entrance channel from the flooded beach in a matter of days (Figure 6, bottom panel). As Hurricane Ike approached the Texas coast, water level rose to a maximum of 1.4 m above MSL at Bob Hall Pier. The surge forced water up to the dune line adjacent to the channel. The water was funneled toward and into the inlet, introducing sand from the adjacent beach into the entrance channel. The water entering the channel maintained a region of constant channel depth (3 m) at about the dune line, while the channel to the east and west filled with sand (Figure 6). Figure 9 shows this same region in cross section. After the storm, nearly 8,000 m^3 of sand was forced out of the entrance channel into the Gulf of Mexico as receding water enhanced ebb flow and winter fronts resumed. By January 2009, a substantial shoal persisted and continued to expand during the remaining mild winter months as southeast winds dominated with few wind reversals to accentuate ebb flow. Over the 5-month period from January 2009 to June 2009, drought and strong southeasterly wind enhanced the transport of wind-blown sand into the channel, and the shoal expanded westward as another 12,000 m^3 of sand was introduced into the channel from the neighboring beach (Figure 7). Over the spring and summer, sand began to migrate into the inner channel during periods of moderate flood flow.

No wind barriers exist between the inlet and the advancing Gulf beach on either side as were recommended in the design study (Kraus and Heilman, 1997). Therefore, wind-blown transport has contributed to shoal growth. The contribution of wind-blown sand to channel shoaling and eventual closure has been documented at Fish Pass located 7.6 km miles to the north (Duke 1985; Shiner, Mosley and Associates, Inc., 1987). During a field study conducted along the beach prior to inlet construction, it was estimated that 19,900 m^3 of sand could potentially enter the entrance channel annually by wind-blown transport if not controlled (Kraus and Heilman, 1997). Despite contributions from storm surge and wind-blown sand, Packery Channel has remained navigable with typical depths of 2 to 3 m, adequate for small recreational vessels for which it was designed. One shallow region (< 2 m) that could limit some deeper draft vessels is confined to the shoal along the south jetty in the entrance channel. Since opening, the deeper section of the

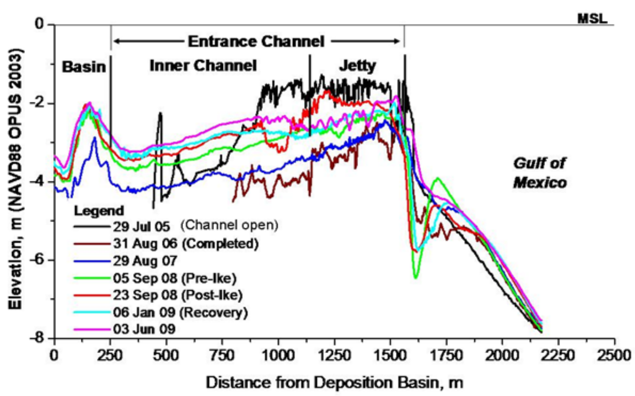

Figure 9. Change in depth along channel centerline (2005-2009).

channel has been preserved along the north jetty, likely due to preferential introduction of wind-blown sand over the south jetty. The entrance channel shoal position and extent compare closely with that of the emergent shoal at Fish Pass in 1982 (Kraus and Heilman, 1997), indicating similar influence of preferential introduction of wind-blown sand from the south beach.

The entrance shoal that formed over the spring of 2009 became the most expansive since the channel opened. Seasonal scour by wind-reinforced current previously limited the extent of westward shoal migration. The growth of the shoal is attributed to the large volume of sand introduced during Hurricane Ike that was later augmented by wind-blown sand entering from the neighboring beach. The greatest contribution of sand is introduced from the south beach due to persistent southeasterly wind, exacerbated by drought. The contribution from the north beach, during frontal systems, to the total volume of sand transported by wind is less than that from the south. This bias is because the winter fronts act over a shorter period of time and only during the winter months, whereas strong southeast wind occurs on a nearly daily basis over the course of most of the year. In addition, winter fronts are often accompanied by rain, reducing sand mobility. Sand introduction from the Gulf of Mexico is limited by moderate to strong ebb flow and a region of deep scour surrounding the shallower channel mouth.

After the jetties and channel were completed during September 2006, depth along the inlet centerline has gradually decreased, with the deepest section consistently in the inner channel near the deposition basin and the shallowest near the channel mouth (Figure 9). The entrance channel is the most dynamic channel segment, experiencing the greatest episodic and seasonal change in depth. The region between the jetties has consistently been shallower than the inner channel since the channel opened in 2005, despite the only dredging conducted of this segment to date done in January 2006 to facilitate construction after Hurricane Emily breached the barrier island. The depth of the entrance channel was at a minimum 2.5 m and maximum of 3.5 m after completion, while the inner channel depth ranged from 4 to 4.5 m. The center channel has maintained navigable depths since 2006. Despite increased shoaling during 2008 and 2009, centerline depth has been maintained in excess of 1.7 m in the entrance channel and greater than 2.3 m in the inner channel.

Nearshore Morphology

Channel Mouth

Since inlet completion in October 2006, shoal formation has been confined to the channel, depositional features being absent in the nearshore fronting the channel mouth (Figures 4, 5, 6, 7). It is remarkable that no ebb-tidal delta has formed off the inlet. Lack of formation of an ebb delta is attributed to a moderate daily ebb flow at the channel mouth, intermittent transport of sand from the channel to the Gulf, strong wave- and wind-generated longshore current with seasonal changes that alternately sweeps sediment away from the mouth, and strong bursts of ebb flow during passage of winter fronts.

Current-induced scour has been a consistent feature around the jetties and channel mouth since jetty construction began. Scour at the end of the jetties is seasonal with reversal from south to north over the summer and winter, respectively, driven by reversals in wind and current direction. Hurricanes and tropical storms can initiate scour reversals at the jetty tips, but over the course of days rather than months. Figure 4 shows an example of seasonal reversal in scour at the jetty mouth that is typical at the end of summer (August 2006) and mid-winter (December 2006). Since the channel opened, scour has been observed at the end of the south jetty during the summer and at the north jetty during the winter. The channel mouth to the Gulf of Mexico has remained scoured regardless of season, with the exception of August 2007 and more recently June 2009 (Figure 5 and 7). Typical seasonal scour did not develop fully at the jetties and thus channel mouth in August 2007. Prior to the August 2007 survey, concrete blocks were placed in the deep scour hole that had increased to a maximum of 7 m around the jetty tip during the summer of 2006. In addition, just two weeks prior to the survey, higher-than-average waves arrived from Tropical Storm Erin that made landfall 48 km north near Rockport, TX. This tropical storm increased scour around the north jetty that is more typical of winter. Scour had resumed at the south jetty, but shifted some 9 m further offshore by early the following summer (June 2008). Depth at the south jetty tip increased from 3.6 m to in excess of 8.5 m at this time. The scour hole migrated across the channel mouth under the influence of strong northerly directed longshore current that is common during the summer season.

The second time that the scour hole at the channel mouth filled was the result of a surplus in sediment supply as the ebb current scoured the expansive entrance shoal from January to June 2009 (Figures 7 and 9). Although scour is evident at the south jetty during June 2009, it is not nearly as well developed as would be expected after 5 months of nearly uninterrupted wind waves forced from the southeast. Absence of scour development is attributed to the entrance shoal functioning as a supply of sand that, when combined with moderate (0.6 to 0.9 m/s) pulses of ebb flow that occurs up to twice daily, amounts to a near steady stream of sand exiting the channel over

the 5-month period. The volume of sand exiting the channel was in excess of the transport capacity of the longshore current; therefore regions where temporary scour likely did develop were quickly filled with sand that was exiting the channel. The depth at the channel mouth was comparable to that measured along the adjacent nearshore (3 - 3.6 m) (Figure 7).

During winter, wind accompanying fronts is directed out of the northwest to northeast. Northwest wind is directed offshore along this section of the coast; therefore, it is the wind out of the north to northeast that drives scour at the north jetty. Scour depths at the north jetty range from 7 to 8 m depending on storm frequency and duration over winter. Scour initiating during winter at the north jetty migrates around the channel mouth due to strong longshore current running from north to south. Scour observed at the channel mouth during the summer and winter is thereby linked to that originating at the jetties as currents reinforce and expand scour in the net direction of the seasonal longshore current. The combined effect of these processes results in a nearly constant region of scour at the channel mouth despite reversals in the focal point at the jetty tips. Scour to depths of 5 to greater than 7 m is common at the channel mouth throughout the year (Figure 9).

The influence of storms on nearshore morphology was evident after Hurricane Ike made landfall on 13 September 2008. Figure 6 shows the position of jetty scour before and after Hurricane Ike. Although Hurricane Dolly (July 2009) contributed to channel scour, it did not cause scour reversal at the jetties because waves were directed out of the southeast, a direction consistent with waves during the summer season. The pre-Ike morphology around the channel mouth is typical of that observed late in the summer, with well-developed scour centered at the south jetty and radiating around the channel mouth. Wind and waves during Ike approached from the north initiating rapid scour at the north jetty over the course of days rather then months as is typical during the winter season. Scour depth at the north jetty increased from approximately 4 m before Ike to 8 m after the storm. Due to the short duration of Hurricane Ike, scour remained at the south jetty, although depth did decrease from 7.6 m before Ike, to 5.5 m after storm influence.

Longshore Bars

The nearshore along this section of coast typically presents three to four longshore bars that build and migrate seasonally (Figures 4, 5, 6, 7). Figure 10 shows the annual variability of the longshore bar position at two locations indicated in Figure 2, near the south jetty and at the south end of the seawall, measured prior to construction of the inlet in 1996 to 23 September 2009. Near the Packery Channel entrance, longshore bars develop to the south as southeast wind drives the longshore current toward the north over the summer. On the south side of the inlet, the maximum offshore extent of bar migration occurs in late August or early September. As wind reversals increase in frequency in October, longshore bars become more defined on the north side of the inlet, and the southern bar tends to migrate onshore. Winter bars are typically well defined by mid-winter (December). Figure 4 shows peak longshore bar development to the south during the summer (August 2006) and the subsequent reversal in bar formation to

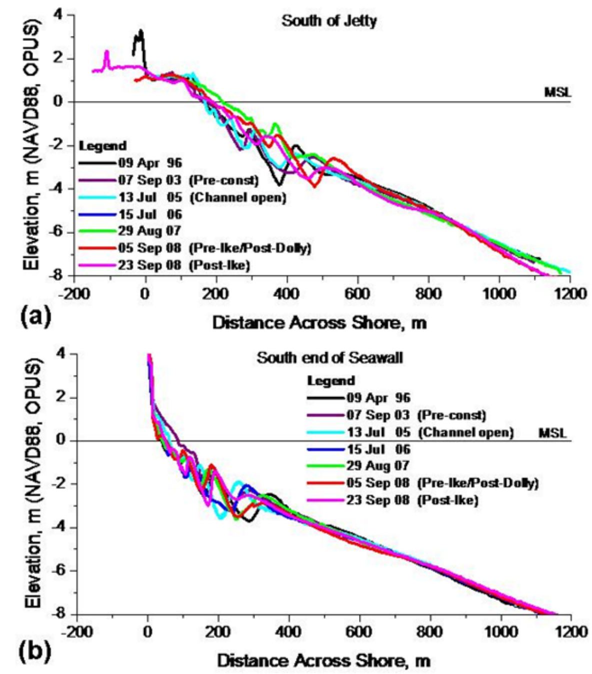

Figure 10. Annual and post-storm variability in longshore bar position located (a) near the south jetty (Transect 1) and (b) at the south end of the seawall (Transect 2).

the north (December 2006) after a series of winter fronts. The longshore bar south of the jetty migrated beyond the jetty tip in June 2008 and September 2008, reaching the maximum northward extent near the inlet mouth (Figures 5 and 6). The maximum offshore position of the outer longshore bar observed since inlet completion occurred at the end of the summer season just before Hurricane Ike (Figures 6 and 10). These seasonal and episodic reversals in longshore sediment transport limit the potential duration of alongshore bar migration near the channel mouth, thereby decreasing the opportunity for ebb delta and bypass bar development.

Shoreline Position and Sediment Transport

Shoreline position was measured along 18 km of Mustang and North Padre Island beach to determine trends in shoreline advance and recession that might be a consequence of inlet construction. The inlet effectively separates Mustang Island from North Padre Island and as of July 2009 trends in nearshore morphology, specifically the absence of bypassing bar formation; indicate that minimal sand is shared across this boundary. The long-term rate of shoreline change is variable along Mustang and North Padre Islands dependent on backshore condition. Morton and Pieper (1977) reported long-term recession occurred along North Padre Island at rates of 0.3 to 1.6 m/yr, with rates of 0.3 to 1.3 m/yr along the southern terminus of Mustang Island at Packery Channel. Gibeaut *et al.*

(2001) report that for the period 1937 to 2000, the long-term average annual rate of recession ranged from 0.5 to 2.5 m/yr with greater rates related found near passes and Bob Hall Pier. The design study for the project (Kraus and Heilman, 1997) indicated that Packery Channel is located at a divergent nodal zone in longshore sand transport. They estimated that the net direction of transport is to the south, with a gross rate of 115,000 to 191,000 m^3/yr and net rate of 34,400 to 53,500 m^3/yr.

Over the study period, 2005-2009, measured shoreline change was variable from the Fish Pass to several kilometers south of Bob Hall Pier. Since 2005, the rate of shoreline change has been influenced by wave sheltering and sediment impoundment adjacent to the jetties, creation of headland beaches by the jetty construction, and placement of sand dredged from the channel to the south beach during April 2005 to July 2005 and subsequently in January 2006. The inlet directly influences the shoreline position within a localized 1-km zone, centered at the inlet, where advance has occurred since 2004. Greatest recession is identified along beaches fronting regions of natural or anthropogenic alteration in the backshore, most specifically, breaks in the dune system. The inlet at Packery Channel and the North Padre Island seawall are examples of such breaks in the dune line along with access roads that function as passes during storm surge. Newport Pass and Corpus Christi Pass are natural passes that interrupt the dune line to the north. Seasonal reversals in wave climate have not influenced shoreline position near the inlet, with both sides advancing during winter and summer. Although significant recession occurred near the inlet during Hurricane Ike, recovery was rapid. In contrast recovery was slower to occur along the remainder of the study area. In contrast, the unsheltered shoreline responds to seasonal change in wave climate with advance and recession occurring during the summer and winter, respectively. Short-term change in beach morphology is also influenced by weekly mechanical redistribution of sand that is conducted by Nueces County beach maintenance crews in an effort to clear soft sand and remove seaweed from the beach. Redistributed sand was frequently placed seaward of the berm crest prior to June 2009, when placement was redirected to the backshore. Analysis presented in the following sections focuses on the region directly impacted by the sheltering effect of Packery Channel and sand placement along the seawall.

Inlet Zone

Within the 1-km zone of observed inlet influence, shoreline advance is observed both to the north and south because of the sand blocking and wave sheltering of the jetties. As the inlet neared completion in 2005, the shoreline had advanced a maximum distance of 100 to 150 m to the south and north, respectively (Figure 11). Advance is nearly symmetric at the inlet, indicating nearly balanced longshore sediment transport, confirming the conclusion of Kraus and Heilman (1997) that the inlet is located in a divergent nodal zone. Such nearly symmetric advance at jetties located in nodal zones has been reported by Komar *et al*. (1976) for inlets in the pocket beaches in Oregon. Initially the south shore advanced more rapidly, in part due to sand placement from April to July 2005 during removal of the backshore of the barrier island for the inlet cut, but also because the incomplete landward end of the north jetty, built after the south jetty, allowed beach sand to enter the channel prior to jetty completion in September 2006. Limited preferential advance adjacent to the north jetty has occurred since September 2007; with the north shoreline located some 50 m seaward of the south shoreline.

Before Hurricane Ike, shoreline advance was greatest near the inlet; during the storm, this region experienced the greatest recession. The inlet zone also recovered more rapidly and more completely than the rest of the study area, with the shoreline approaching pre-storm position within just 3 months after the storm. The post-storm survey, conducted just over a week after the storm made landfall (13 September 2009), showed that the shoreline next to the inlet was located between the 2003 and 2005 position (Figure 11). During Hurricane Ike, the south and north shorelines receded a maximum of 80 to 100 m, respectively, as sand from the beach was forced into the entrance channel. This hypothesis is based upon post-storm (the beach was completely inundated during the storm) field observation of pathways of transport over the jetties and decreased elevation of the adjacent beach. Changes in morphology during Ike do not indicate that a significant volume of sand directly entered the channel mouth from the Gulf of Mexico. In addition, a region of scour is indicated in channel bathymetry and along the post-storm centerline plot where water forcibly entered the channel from the sides with shoaling well developed both to the east and west of the point of entry (Figures 6 and 9). After the storm, the beach recovered as sand exited the channel and re-entered the nearshore bar system which functioned as the repository for sand lost offshore during Ike. Within 3 months (January 2009), the shoreline advanced some 40 to 60 m seaward of the post-storm (September 2008) position, and by April 2009 the shoreline both north and south was approaching the pre-storm position. By July 2009, the north shoreline had advanced seaward of the pre-storm position, while the southern shoreline was stable and within 10 to 20 m of its pre-storm position. The symmetry of shoreline position change was maintained both during the pre-Ike transition as well as during the post-storm recovery period.

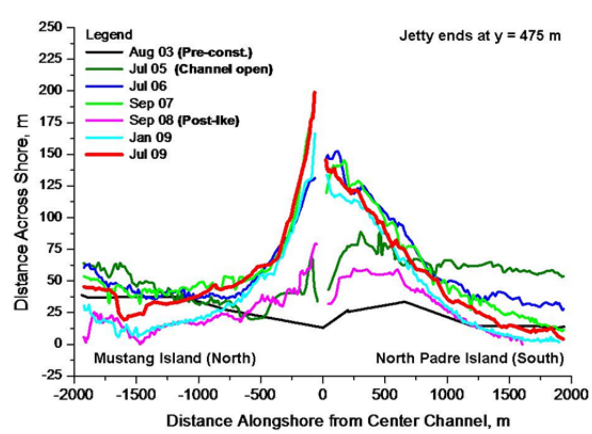

Figure 11. Shoreline position change near the inlet (2003-2009).

North Padre Island Seawall

After the North Padre Island seawall was constructed (without permitting authority) during the early 1960s, the beach fronting it has eroded and limits public access. The 1.3-km long seawall fronts a region of historic breaches by former pathways of Packery Channel. The seawall is bound by two access roads, Access Road 3A to the north and Whitecap Blvd. to the south. Both of these access roads flood during elevated water level accompanying storms. The beach is so narrow at the south end of the seawall that washover at Whitecap Blvd. promotes erosion there. Maximum beach width, measured from the intersection with the seawall, during sand placement in 2005, gradually increases from 52 m at the south end to over 61 m along the north end (Figure 11). The shoreline receded over the course of the next year as the beach responded to surge and waves generated by Hurricanes Rita and Katrina followed by winter storm waves. In January 2006, a small amount of sand that had been removed from the entrance channel to provide for barge access and facilitate construction was transported to the historically narrow beach in front of the seawall and Whitecap Blvd. In contrast, the south jetty provides shelter to the beach along the north end of the seawall with influence extending to near the mid-point of the seawall. From that point southward, by September 2007, shoreline position approached or receded landward of the 2003 pre-construction position.

The shoreline receded along the full length of the seawall during Hurricane Ike at equivalent rates to that observed elsewhere in the study area. Because the beach was narrow, only 12 m wide fronting the south-end of the seawall, storm surge and wave action during Hurricane Ike was directed along the beach and seawall intersection. In response, the beach eroded, and the shoreline receded up to the seawall. After the storm, the seawall effectively marked the shoreline position. The surge forced water and sand through the narrow gap in the dunes formed by Whitecap Blvd. As the water flowed seaward, erosion of the beach fronting the access road was exacerbated, and the shoreline receded 15-m landward of the seawall position. The beach fronting the north-end of the seawall remained some 24 m seaward of the 2003 baseline, attributed to the greater pre-storm beach width. After Hurricane Ike, the beach began a slow recovery with shoreline advance approaching the January 2006 position by January 2009. By July 2009, the shoreline had advanced 3 m (south end) to greater than 15 m from the mid-point of the seawall northward. Shoreline advance along the seawall occurred two times during the study period; 1) during construction and active sand placement, and 2) during beach recovery after Hurricane Ike (January to June 2009).

Rate of Shoreline Change

The rate of shoreline change is greatest adjacent to the inlet, along the seawall, and fronting ephemeral inlets or other large breaks in the dune system (Figure 12). The rate of shoreline change was calculated along the study area over two distinct periods; 1) Baseline (July 2005-September 2007), and 2) Post-construction (July 2005-June 2009). The baseline period is included in order to isolate the transition period after construction and before the impact of Hurricane Ike. Although data are available since 2003, the 2005 data set is considered to represent the post-construction state of the beach. The post-construction period reflects change occurring after construction, during Hurricane Ike, and continuing through post-storm recovery.

From July 2005 to September 2007, shoreline change was characterized by maximum advance at the jetties at a rate of 40 m/yr (south) to 60 m/yr (north) and maximum recession at 2 m/yr along the south-end of the seawall. Isolated regions of high recession with rates ranging from 5 to 10 m/yr were identified at to the north at Newport Pass and to the south at Bob Hall Pier. Shoreline advance occurred across the study area from July 2005 to September 2007 at a rate of 0.9 m/yr, as the shoreline adjusted in response to completion of the jetties and sand placement at the south end of the seawall. Over this baseline period, the rate of shoreline advance along the north zone of influence (10 m/yr) was greater than along the south zone (3.3 m/yr) as sand was impounded by the recently completed north jetty. The rate of shoreline advance along the seawall from July 2005 to September 2007 was 12 m/yr, which included the redistribution of sand placed at the south end of the seawall.

Although post-storm recovery occurred rapidly in the inlet zone of influence, the shoreline along the remainder of the beach, particularly along the seawall, had still not advanced completely to the pre-storm position by July 2009. Therefore, despite the rapid advance of the shoreline adjacent to the jetties at a rate of 9.5 m/yr to the north and 5.5 m/yr to the south, net recession occurred over the post-construction monitoring period from 2005 to 2009 at an average rate of 1.6 m/yr. There is greater longshore variability in the rate of shoreline change over the entire period of study from completion of Packery Channel (July 2005) through post-Ike recovery (July 2009). Regions experiencing the greatest rates of transport remained consistent between the brief baseline period and the longer post-construction period (Figure 12).

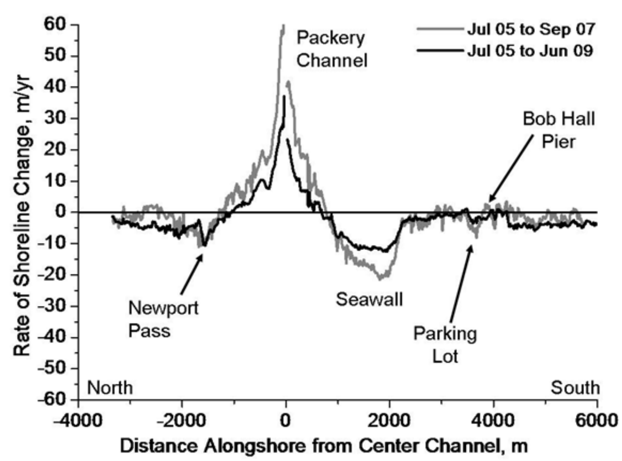

Figure 12. Rate of shoreline change (2005-2009) relative to features in the study area.

Prior to the Hurricane Ike, shoreline advance was observed along the study area as the newly constructed jetties provided shelter extending up to 1 km along the adjacent beach. Although the rate of change is comparable along the north and south beach, there is little indication of sediment sharing as the inlet forms a headland type feature separating processing acting at the two beaches. Although the region next to the inlet recovered rapidly after Hurricane Ike, the remainder of the beach, particularly fronting the south end of the seawall, was located well landward of the pre-storm position.

CONCLUSIONS

Six years of monitoring of shoreline position, beach profile, and bathymetry has revealed expected and unexpected morphologic responses to construction of Packery Channel, TX, an inlet connecting Corpus Christi Bay to the Gulf of Mexico. Many of the inlet processes can be understood from knowledge of two distinct wind regimes along the Texas coast, when the wind blows primarily from the southeast in the summer, and when winter fronts come in from the north. Wind out of the northeast alters the direction of longshore transport, whereas winter fronts out of the northwest set up the bay in the southeast corner and reinforce ebb flow through Packery Channel. Episodic morphologic change at the inlet during tropical storms and hurricanes has been found to reproduce trends in seasonal changes in morphology.

Perhaps the most interesting response is a null one – no ebb delta has formed, despite the presence of tidal ebb flow enhanced by the current induced by winter fronts. It is our interpretation that strong wave-induced longshore currents from opposite directions according to wind regime, and associated alternate longshore bar formation, sweep sand from the entrance, not allowing a persistent general morphologic feature to form. Absence of an ebb delta is also attributed to lack of consistent sand source from the channel and bay to supply material that can be transported offshore, and strong bursts of ebb flow during passage of winter fronts.

The nearshore bathymetry also responds seasonally, showing longshore bars that grow toward the inlet from the north during winter and dissipate in summer, and longshore bars that grow toward the inlet from the south in the summer and dissipate in winter. Seasonal erasure of bars reduces longshore transport toward the inlet and therefore limits navigation channel infilling from the Gulf. Scour holes appear at the north and south jetties in winter and summer, respectively, contributing to transport of sediment away from those structures.

The channel has been slowly shoaling, but no maintenance dredging has yet been necessary for supporting shallow-draft recreational navigation. Efficiency of the channel is attributed to its large width-to-depth ratio, and to the action of wind-induced setup in the southeast corner of Corpus Christi Bay, which reinforces ebb-tidal flow and can reverse a typical flood-tidal current. The favoring of stability of a so-called southeast corner (of a bay) pass or inlet on the Texas coast due to orientation of the coast and occurrence of strong and numerous wind fronts was pointed out by Price (1952). These processes were accounted for in design of the inlet.

Another factor promoting stability of the inlet is that it is located in a nodal zone of longshore transport, from which sand tends to be transported to the north in summer and to the south in winter. This balance in transport has produced a near-symmetric fillet growth at the jetties, a phenomenon first pointed out by Komar *et al*. (1976) for inlets located in nodal zones.

Initial shoaling in the deposition basin and at the intersection with the inner channel was identified as originating from erosion of the channel section north of the SH361 Bridge; sediment depositing in the basin as strong ebb flow weakens upon entering a wide area. Shoal formation was also exacerbated by localized introduction of sand by wind and runoff from the boat basin parking area before paving was completed.

Wind-blown sand has been identified as a major source of shoaling in the entrance channel, along with early contributions from the neighboring beach through an opening near the shoreline in the north jetty that remained for supporting jetty construction. More recent shoaling in the entrance channel and inner channel occurred rapidly as sand entered the channel over the low jetties during Hurricane Ike. This storm-induced introduction of beach sand was followed by 5 months of nearly constant and unobstructed wind-blown transport of sand from the south beach during an extended period of drought.

Surveys of shoreline change after Hurricane Ike indicate rapid recovery near the inlet and slower recovery over the remainder of the study area, particularly at breaks in the dune line and along the south end of the seawall. Seasonality of shoreline position change has been limited thus far at the inlet, but the shoreline along the unsheltered beach typically recedes during the winter months followed by summer advance. Isolated sand placement (conducted during preparation of this paper) as the basin was dredged near the boat ramp may alleviate access restrictions for a short period, but in the long term cannot overcome a trend for shoreline recession in that area.

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LITERATURE CITED

Behrens, E.W.; Watson, R. L., and Mason, C., 1977. Hydraulics and dynamics of Corpus Christi Water Exchange Pass, Texas, *GITI REPORT* 8. Ft. Belvoir, Virginia: U.S. Army Corps of Engineers Coastal Engineering Center, 126p.

Behrens, E.W., 1979. New Corpus Christi Pass, a Texas tidal inlet. *Shore & Beach* 47(4), 9-14.

Brown, C.A. and Militello, A., 1997. Packery Channel feasibility study: Bay circulation and water level. Report 2 of

a two-part series. Technical Report TAMU-CC-CBI-96-07, Corpus Christi, Texas: Texas A&M University-Corpus Christi, Conrad Blucher Institute for Surveying and Science, 57p.

Duke, J.H., 1985. Fish Pass analysis–preliminary results. *Personal Letter to Dr. Joe C. Moseley,* Goldston Engineering, Corpus Christi, Texas, 6p.

Collier, A. and Hedgpeth, J. W., 1950. An introduction to the hydrography of tidal waters of Texas. *Publications of the Institute of Marine Science*, Austin, Texas: The University of Texas, 1(2): 124-194.

Gibeaut, J.C.; Hepner, T.; Waldinger, R.L.; Andrews, J.R.; Gutierrez, R.; Trembley, T.A., and Smyth, R.C., 2001. Changes in Gulf shoreline position, Mustang and North Padre Islands, Texas. Texas Coordination Council Final Report pursuant to National Oceanic and Atmospheric Administration, under award No. NA97OZ0179 and TGLO contract No. 00-002R, Austin, Texas: The University of Texas, Bureau of Economic Geology, 30p.

Heise, E.A.; Benavides, J.A.; Contreras, M.; Cardoenas, A., and Lemen, J., 2009. Hurricanes Dolly and Ike damaged the Town of South Padre Island from the Gulf Side and the bay side in 2008, *Shore & Beach* 77(2), 30-36.

Komar, P.D.; Lizarraga-Arciniega, J.R., and Terich, T.A., 1976. Oregon coast shoreline changes due to jetties. *Journal of Waterways, Harbors and Coastal Engineering* 102(WW1): 13-30.

Kraus, N.C., 2007. Coastal inlets of Texas, USA. *Proceedings Coastal Sediments '07*, N.C. Kraus and J.D. Rosati (eds.), ASCE, Reston, Virginia, 1,475-1,488.

Kraus, N.C. and Heilman, D.J., 1997. Packery Channel feasibility study: Inlet functional design and sand management. Report 1 of a two-part series. Technical Report TAMU-CC-CBI-96-06, Corpus Christi, Texas: Texas A&M University-Corpus Christi, Conrad Blucher Institute for Surveying and Science, 106p.

Kraus, N.C. and Heilman, D.J., 1998. Comparison of beach profiles at a seawall and groins, Corpus Christi, Texas. *Shore & Beach* 66(2):4-13

Kraus, N.C. and Lin, L., 2009. Hurricane Ike along the upper Texas coast: An Introduction. *Shore & Beach* 77(2), 3-8.

Lohse, E.A., 1952. Shallow-marine Sediments of the Rio Grande Delta. Austin, Texas: University of Texas at Austin, Ph.D Dissertation, 114p.

Price, W.A., 1952. Reduction in maintenance by proper orientation of ship channels through tidal inlets. *Proceedings 2nd Coastal Engineering Conference*, Council on Wave Research, 243-255.

Shiner, Mosley and Associates, Inc., 1987. Draft environmental assessment on reopening of Packery Channel, J7038. Prepared for Fish Trackers Inc./Reopen Packery Channel Association, Corpus Christi, Texas.

Stone, W., 2006. The evolution of the National Geodetic Survey's Continuously Operating Reference Station (CORS) network and Online Positioning User Service (OPUS), *Proc. 2006 ION-IEEE Position, Location, and Navigation Symp.*, April 25-27, San Diego, California, 653-663.

Tirpak, S.M., 2009. United States Army Corps of Engineers, Galveston District: Operational experiences and response to Hurricane Ike. *Shore & Beach* 77(2), 60-70.

Watson, R L. and Behrens, E.W., 1976. Hydraulics and dynamics of New Corpus Christi Pass, Texas: A Case History, 1973-75. GITI Report 9. Prepared for U. S. Army Coastal Engineering Research Center, Vicksburg, Mississippi, 175 p.

Williams, D.D.; Kraus, N.C., and Anderson, C.M., 2005. Baseline and construction monitoring of Packery Channel, Corpus Christi, Texas. *Proc. Florida Shore and Beach Preservation Association,* http://www.fsbpa.com/publications.html, 16pp.

Williams, D.D.; Kraus, N.C., and Anderson, C.M., 2007. Morphologic response to a new inlet, Packery Channel, Corpus Christi, Texas. *Proceedings Coastal Sediments '07*, N.C. Kraus and J.D. Rosati (eds.), ASCE, Reston, Virginia, 1,529-1,542.